Department of Mechanical Engineering
Modular Sterile Cleanroom
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ME476C Section 1 Fall 2023

To: Dr. David Willy
From: Michelle Borzick
Date: 12-6-23
Re: HW04 Individual Analysis

Introduction

For our modular sterile cleanroom design, we have not yet determined what height the wall gap between the bottom of the polycarbonate walls and the floor should be. The current cleanroom design has inconsistent wall heights at around 12′′, but there is no indication in the previous capstone group's reports as to why they chose 12′′. Additionally, we have not determined which setting the fan filter unit (FFU) should be set at. This Computational Fluid Dynamics (CFD) analysis will attempt to understand which wall gap height (4", 6′′, 8′′, or 12′′) and which fan speed (high, medium, low) the FFUs should be placed at to maintain the cleanroom ISO Class 7 requirements for velocity air flow.

The method I used to compare the different fan speeds with wall gap heights was an Ansys CFX simulation. Some assumptions I made throughout the simulation were: simplified geometry accurately represents the actual cleanroom, the FFUs uniformly produce the manufacturer's specified air flow, air will flow uniformly through the cleanroom and evenly distribute among the outlets, and lastly that all four sides of the cleanroom are open to the room which will not be perfectly represented in our actual cleanroom since we will be attaching to a gowning room. For the simulations, first I created simplified models of the 12x16 cleanroom with the 4 FFUs placed in the appropriate locations for each of the wall gap heights as shown in **Figures 1** through **3**. The models are solid geometries of the cleanroom instead of open like the actual cleanroom would be. The solid geometries consist of layers, the top of the cleanroom, the wall height gap, and a 1.5′′ floor that mimics the heights of the 1.5′′ aluminum tubing sitting on the floor of the cleanroom. This simplification helped isolate the inlets and outlets better and create a less complicated mesh for the streamline simulations.

Figure 1: 12′′ Wall Gap **Figure 2**: 8′′ Wall Gap **Figure 3**: 6′′ Wall Gap

For each CFX simulation Mesh section, I used the default mesh settings and created named selections for the inlet and outlet. For the inlet I assigned all the FFU placements on the ceiling of the cleanroom and for the outlet I assigned the wall gap height. An example of one of the mesh setups is shown in **Figure 4**.

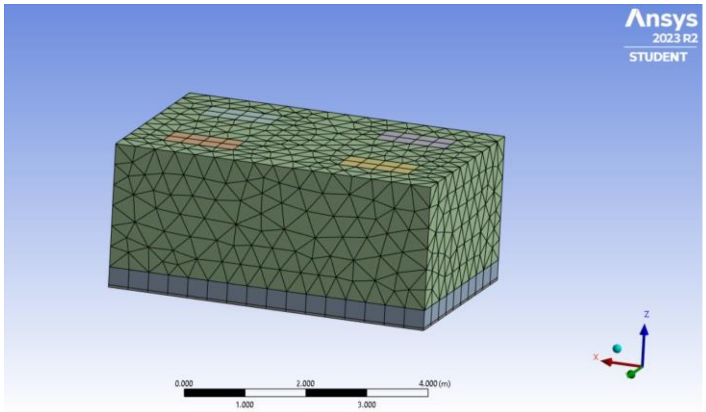

Figure 4: Mesh Setup

For the Setup section, I created an inlet and outlet boundaries where I assigned the previously created named selections. An example of the inlet and outlet boundaries is shown in **Figure 5**.

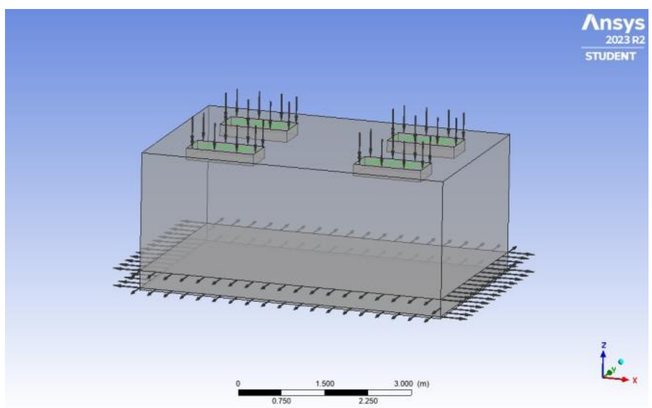

Figure 5: Boundary Conditions

For the inlet boundaries, I calculated the expected output velocities from the FFU at different speeds given the manufacturer's specifications for air flow shown in **Table 1** [1]. We will be using the first listed 2′ x 4′ HEPA FFU.

Table 1: Expected Air Flow Specifications for FFU

WHISPERFLOW® FFU PERFORMANCE DATA					
Nominal Unit Size (ft.)	Filter	Sound (dB) @90FPM	AIR FLOW (CFM)		
			HIGH	MED	LOW
2′ x 4′	HEPA	49	800	720	590
2′ x 4′	HEPA (RSR)	49	800	720	590
2′ x 4′	ULPA	49	660	640	580
2′ x 4′	ULPA (RSR)	49	660	640	580
2′ x 3′	HEPA	49	675	630	560
2′ x 3′	HEPA (RSR)	49	600	560	540
2′ x 2′	HEPA	49	450	440	420
2′ x 2′	HEPA (RSR)	49	360	330	300

Using the given air flows in ft^3/min for each of the four FFUs and the total cleanroom area under the FFUs in ft^2, I calculated the expected output velocity of each FFU setting **(1)**. I used these expected velocities as the inlet velocities leaving the FFUs. For the outlet velocities, I chose the lower specification limit of 10 ft/min (0.051 m/s) to be conservative [2].

$$\text{High: } V = \frac{Q}{A} = \frac{4(800)}{12(16)} = 16.67\ ft/min\ (0.0847\ m/s)$$
$$\text{Medium: } V = \frac{Q}{A} = \frac{4(720)}{12(16)} = 15\ ft/min\ (0.0762\ m/s)$$
$$\text{Low: } V = \frac{Q}{A} = \frac{4(590)}{12(16)} = 12.29\ ft/min\ (0.0624\ m/s) \quad \textbf{(1)}$$

For the streamline simulation, I selected the inlets as the velocity source and set the number of streamlines to 1000 to see the full effect while still being able to see the individual streamlines. I repeated the simulation process for all twelve combinations of wall gap height and FFU speed. The three 4′′ streamlines for high, medium, and low are shown in **Figures 6** through **8**.

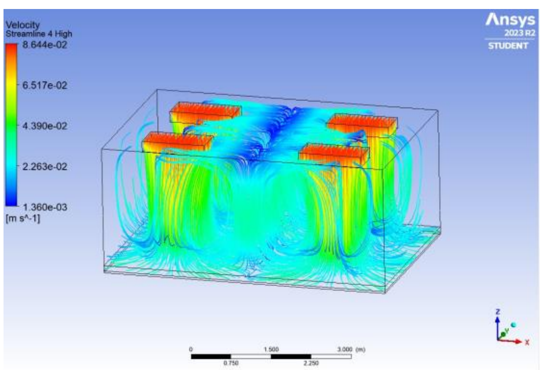

Figure 6: Streamline 4″ Gap High Speed

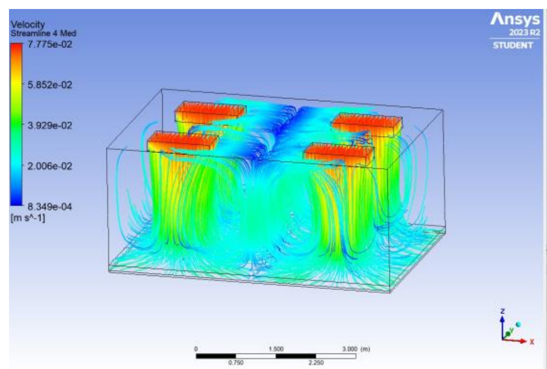

Figure 7: Streamline Gap 4″ Medium Speed

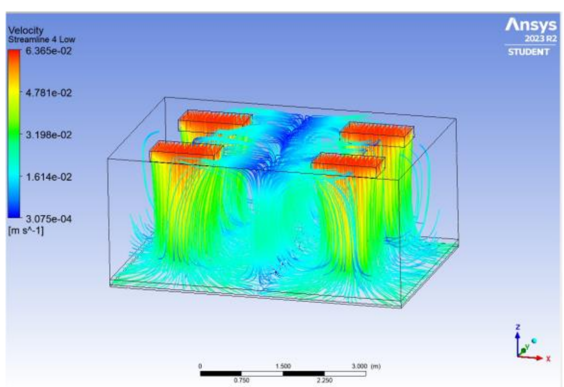

Figure 8: Streamline 4″ Gap Low Speed

The three 6′′ streamlines for high, medium, and low are shown in **Figures 9** through **11**.

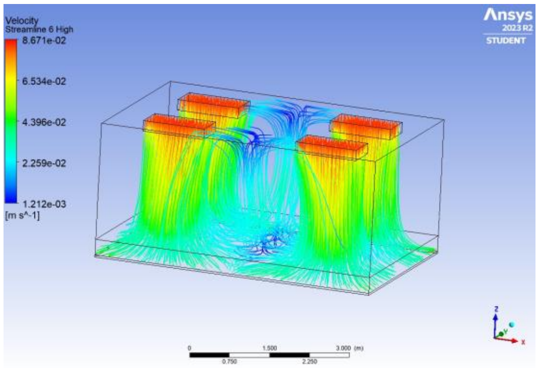

Figure 9: Streamline 6″ Gap High Speed

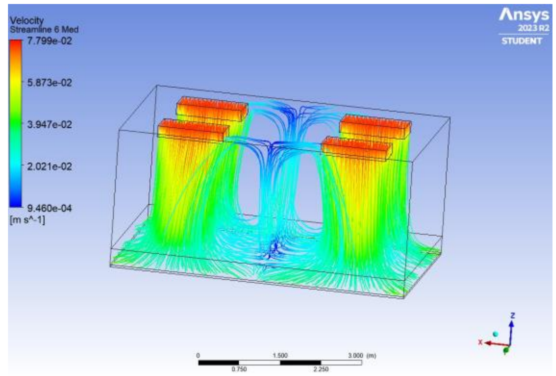

Figure 10: Streamline Gap 6″ Medium Speed

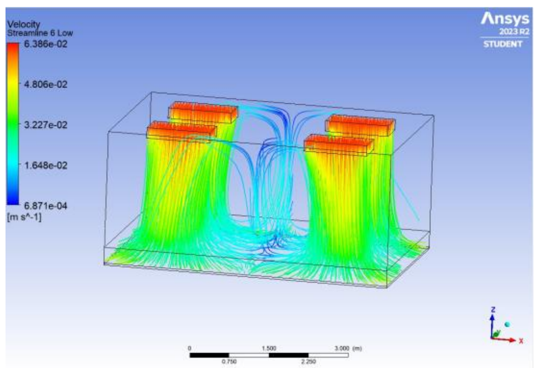

Figure 11: Streamline 6″ Gap Low Speed

The three 8′′ streamlines for high, medium, and low are shown in **Figures 12** through **14**.

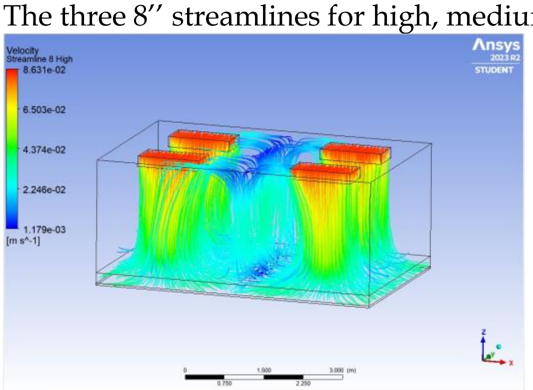

Figure 12: Streamline 8″ Gap High Speed

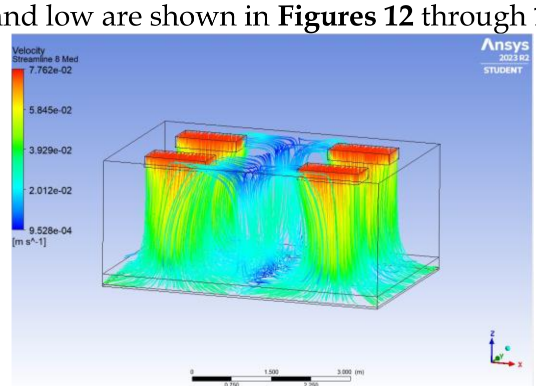

Figure 13: Streamline Gap 8″ Medium Speed

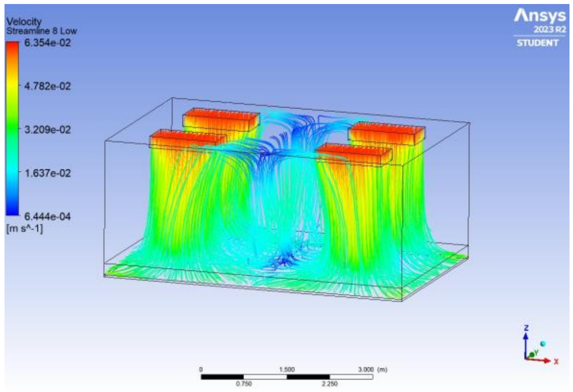

Figure 14: Streamline 8″ Gap Low Speed

The three 12′′ streamlines for high, medium, and low are shown in **Figures 15** through **17**.

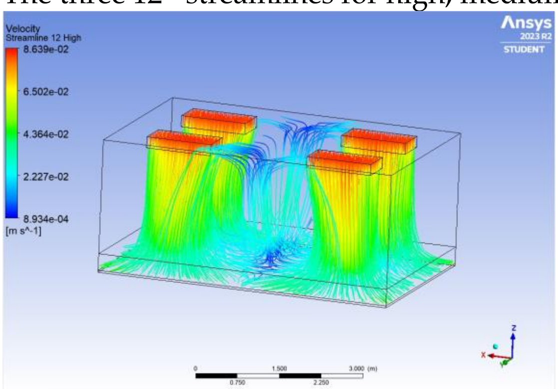

Figure 15: Streamline 12″ Gap High Speed

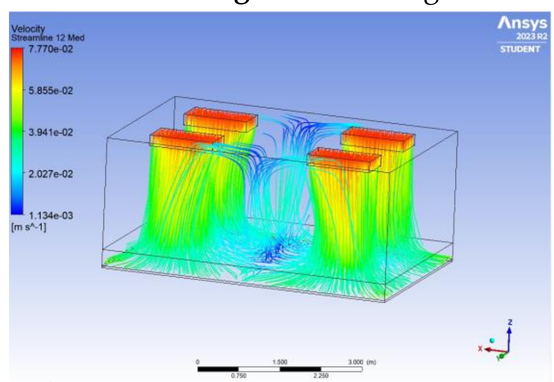

Figure 16: Streamline Gap 12″ Medium Speed

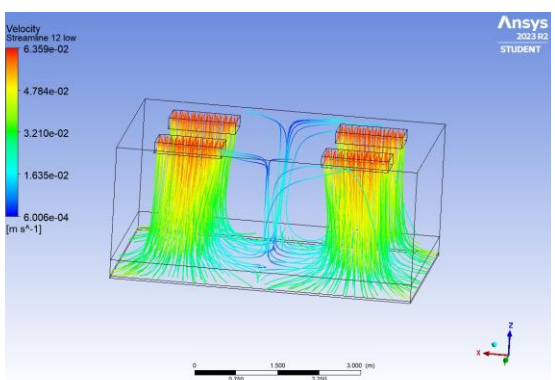

Figure 17: Streamline 12″ Gap Low Speed

I summarized the exit velocity ranges from each of the simulations and calculated the average velocities for each wall height and FFU speed combination using the green to red velocity ranges from the simulation. The blue range shows lingering turbulent air and does not represent the majority of the air exiting the cleanroom.

The specifications for ISO Class 7 cleanrooms require the average velocity to be from 0.051 – 0.076 m/s. Higher average velocities indicate a higher class ISO Class cleanroom which is unnecessary for our cleanroom design but still acceptable. The specifications will thus be treated as lower specification limits but not higher specification limits. The average velocity and air changes per hour calculations are shown in **Table 2** with a conclusion on if the wall height and FFU speed setting combination meets specifications.

Table 2: Summary of Results:

Wall Height	FFU Speed	Exit Velocity Range (m/s)	Average Velocity (m/s)	Above Velocity Specifications (0.051 m/s)
4″	High	0.04390 – 0.08644	0.0652	Yes
4″	Medium	0.03929 – 0.07775	0.0585	Yes
4″	Low	0.03198 – 0.06365	0.0478	No
6′′	High	0.04396 – 0.08671	0.0653	Yes
6′′	Medium	0.03947 – 0.07799	0.0587	Yes
6′′	Low	0.03227 – 0.06386	0.0481	No
8′′	High	0.04370 – 0.08631	0.0650	Yes
8′′	Medium	0.03929 – 0.07762	0.0585	Yes
8″	Low	0.03209 – 0.06354	0.0478	No
12″	High	0.04364 – 0.08639	0.0650	Yes
12″	Medium	0.03941 – 0.07770	0.0586	Yes
12″	Low	0.03210 – 0.06359	0.0478	No

Based on the calculated average velocities, it appears that wall height gap does not matter to pass velocity specifications. It also appears that the FFU can be placed on medium or high speed with any of the wall gap heights. Since we will likely have a choice on the wall height gap, we will likely choose the 12” wall height gap since it will use less materials and appears to be less turbulent overall. The smaller gap cleanrooms have significantly more slow-moving air trapped in the cleanroom that causes increased turbulence. The turbulence, although it does not impact the air velocity, could affect the future particle testing. For the FFUs speed, we will likely choose to keep the FFUs on medium. Since we are currently planning on designing an automatic backup battery system, having the FFUs pull less power may allow us to save money on a battery.

References

[1] “Air flow rates,” Cleanroom Air Flow Rates - Clean Rooms West, Inc., https://www.cleanroomswest.com/air-flow-rates/ (accessed Dec. 4, 2023).

[2] “WhisperFlow® fan filter units,” Cleanroom Fan Filter Units, https://www.terrauniversal.com/whisperflow-fan-filter-units.html (accessed Dec. 4, 2023).